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CHEMISTRY
HIGHER LEVEL
PAPER 3

Candidate session number

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Friday 17 May 2013 (morning)

1 hour 15 minutes

Examination code

2	2	1	3	–	6	1	0	9

INSTRUCTIONS TO CANDIDATES

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all of the questions from two of the Options.
- Write your answers in the boxes provided.
- A calculator is required for this paper.
- A clean copy of the ***Chemistry*** *Data Booklet* is required for this paper.
- The maximum mark for this examination paper is *[50 marks]*.

Option A — Modern analytical chemistry

A1. Compound **P** contains a carbonyl group (C=O) and has the molecular formula C_3H_6O.

(a) Draw the **two** possible structures of compound **P**. *[1]*

(b) Explain why the infrared spectra of the structures in (a) are very similar. *[1]*

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(c) Explain how the mass spectra of the structures in (a) can be used to distinguish between them. *[2]*

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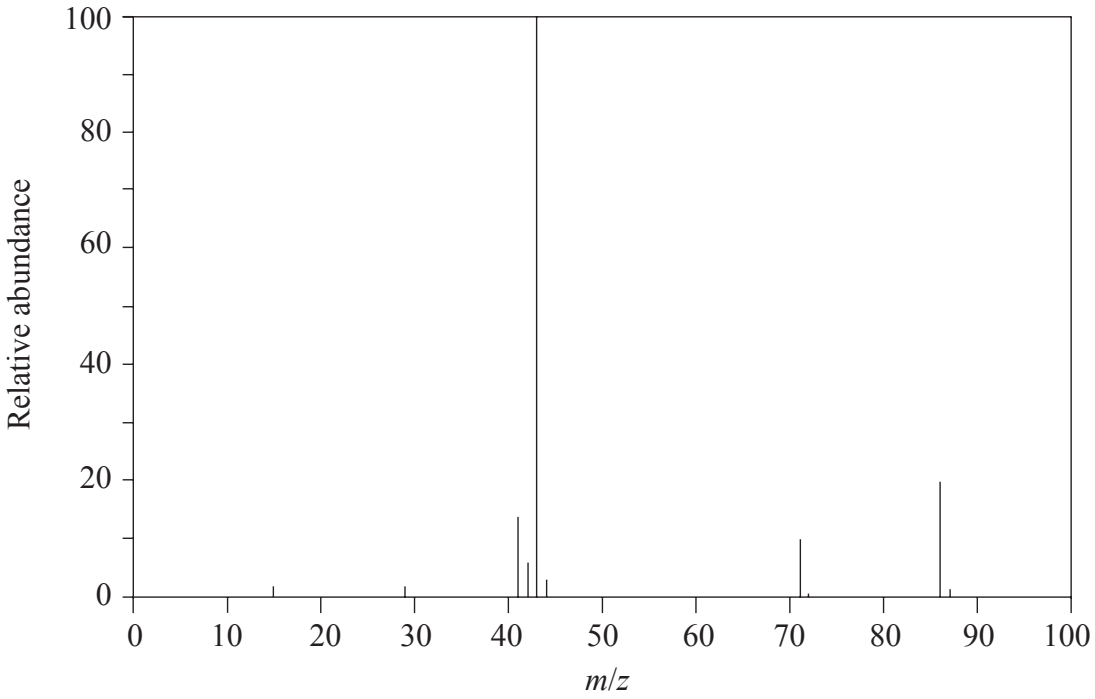
(This question continues on the following page)

(Question A1 continued)

(d) Pentan-2-one has the following mass spectrum.

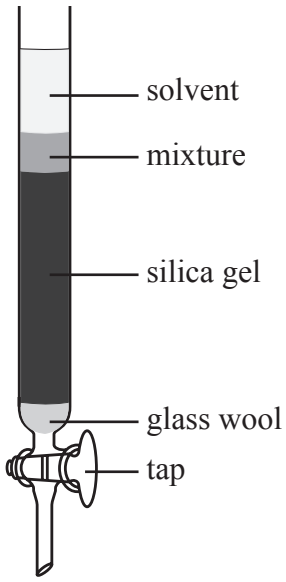


Deduce the formulas of the species with the *m*/*z* values at 71 and 43. *[2]*

m/*z* = 71: . . . . . .

m/*z* = 43: . . . . . .

A2. The diagram shows the apparatus used in column chromatography.



(a) A mixture is run through a chromatography column. Explain how the components of the mixture are separated. *[3]*

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(This question continues on the following page)

(Question A2 continued)

(b) Gas-liquid chromatography (GLC) is also used to separate mixtures. Outline how this technique operates. *[4]*

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(c) Deduce whether GLC can be used to separate a mixture of sugars, including a reason. *[1]*

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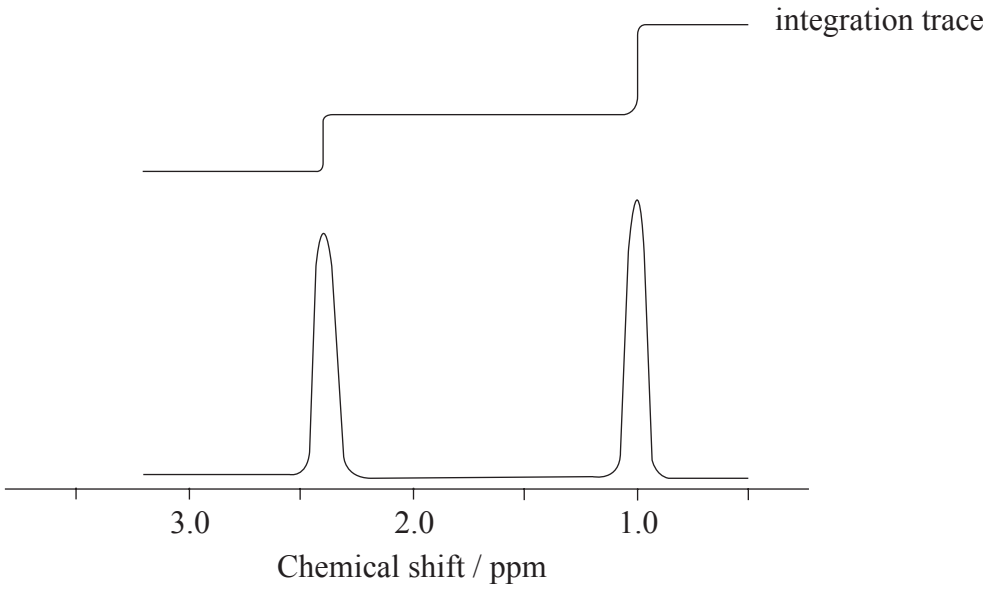
A3. The low resolution ^{1}H NMR spectrum of compound **Q** is shown.



(a) Identify what information from the spectrum allows the determination of the relative numbers of hydrogen atoms producing each peak. *[1]*

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(b) Deduce which of the following compounds is **Q**. *[1]*

$CH_3CH_2CH_3$ $CH_3CH_2COCH_2CH_3$ CH_3CH_2OH

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. . . . . .

(c) Predict the splitting pattern for the peak at a chemical shift of 2.4 ppm. *[1]*

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A4. The electromagnetic spectrum is given in Table 3 of the Data Booklet.

Different types of electromagnetic radiation are used to excite atoms and molecules.

(a) Identify the type of radiation

(i) whose photons have the lowest frequency. *[1]*

. . . . . .

(ii) that causes molecules to rotate faster. *[1]*

. . . . . .

(b) Visible radiation causes electronic transitions in atoms. These transitions are responsible for absorption and emission spectra. Identify **one** similarity and **one** difference in the appearance of absorption and emission spectra. *[2]*

Similarity:

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. . . . . .

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Difference:

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A5. Aqueous ions of iron(III) form a red complex ion with the thiocyanate ligand. Consider the data obtained from the analysis of this complex ion using visible spectroscopy.

Figure 1: Absorbance against wavelength of light

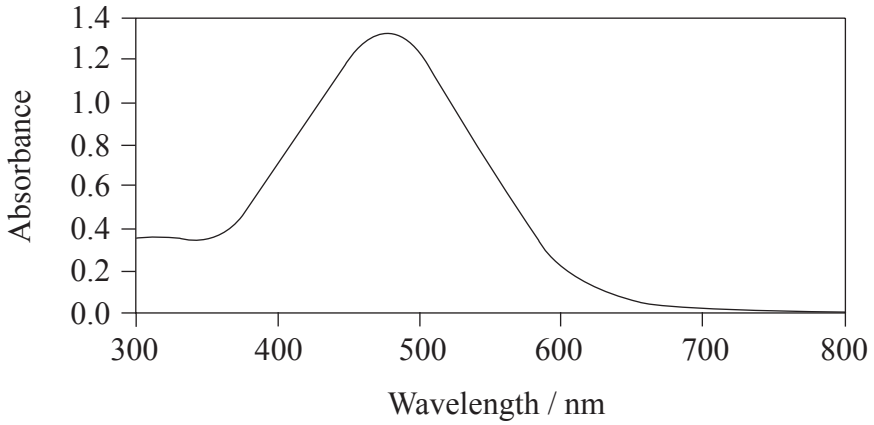
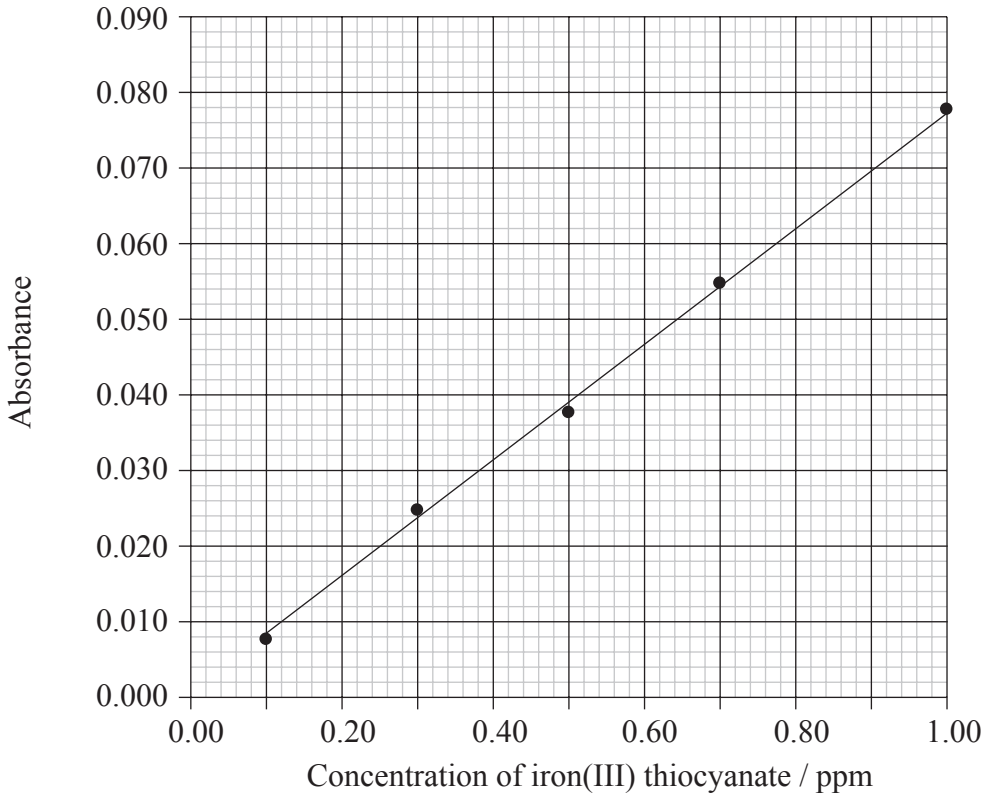


Figure 2: Absorbance of light of wavelength 470 nm at different concentrations of iron(III) thiocyanate



[Source of both figures: Chan *et al*., *Chemical Education Journal* (CEJ), Vol. 7, No. 2, Registration No. 7–18, received October 27, 2003, http://chem.sci.utsunomiya-u.ac.jp/v7n2/choi/choi.html. Figure 2 was re-plotted based on the data in the source.]

(This question continues on the following page)

(Question A5 continued)

(a) Figure 1 shows that a solution of iron(III) thiocyanate has maximum absorbance at a wavelength of 470 nm. State **three** factors that affect the wavelength of radiation absorbed by a transition metal complex. *[2]*

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. . . . . .

(b) State how the calibration curve in Figure 2 agrees with the Beer-Lambert law. *[1]*

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(c) Use the calibration curve in Figure 2 to determine the concentration, in ppm, of an iron(III) thiocyanate solution that has an absorbance of 0.050. *[1]*

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Option B — Human biochemistry

B1. Proteins are formed during condensation reactions of 2-amino acids.

(a) (i) Using Table 19 of the Data Booklet, deduce the structural formulas of the **two** dipeptides formed by the reaction of leucine (Leu) with valine (Val). *[2]*

Dipeptide 1:

Dipeptide 2:

(This question continues on the following page)

(Question B1 continued)

(ii) State the other substance formed during this reaction. *[1]*

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(b) Explain how amino acids can be analysed using electrophoresis. *[4]*

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(c) List **two** functions of proteins in the body. *[1]*

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B2. Monosaccharides and disaccharides are classes of carbohydrates.

(a) Describe the structural features of monosaccharides. *[2]*

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(b) (i) Draw the structures of α-glucose and β-glucose. *[2]*

α-glucose β-glucose

(ii) Two α-glucose molecules condense to form the disaccharide maltose. Draw the structure of maltose. *[1]*

B3. The structures of retinol (vitamin A) and vitamin D are given in Table 21 of the Data Booklet.

(a) Deduce whether each vitamin is water-soluble or fat-soluble and explain your answer by referring to their structures. *[2]*

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(b) State the name of a condition or disease that may be prevented by eating cereals that have vitamin D added to them. *[1]*

. . . . . .

B4. Enzymes are biological catalysts. Catalases are highly efficient enzymes found in cells. Each catalase molecule can decompose millions of hydrogen peroxide molecules per second.

Metal-based inorganic catalysts are also common. In 2009, at Cardiff University in Wales, a new catalyst was developed by Hutchings and co-workers using gold–palladium nanoparticles in the direct synthesis of hydrogen peroxide.

(a) (i) Describe the characteristics of an enzyme (such as catalase). *[2]*

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. . . . . .
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. . . . . .

(ii) Compare its catalytic behaviour to a metal-based inorganic catalyst (such as palladium). *[2]*

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(This question continues on the following page)

(Question B4 continued)

(b) Enzymes are affected by inhibitors which can be either competitive or non-competitive.

(i) State how inhibitors affect the initial rate of reaction of an enzyme with its substrate. *[1]*

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. . . . . .

(ii) Explain the action of competitive and non-competitive inhibitors on enzymes in terms of where the inhibitor binds to the enzyme. *[2]*

Competitive inhibitors:

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. . . . . .
. . . . . .

Non-competitive inhibitors:

. . . . . .
. . . . . .
. . . . . .

(iii) State how inhibitors affect the values of V_{max} and the Michaelis constant, K_m, by completing the table below. *[2]*

	V_{max}	K_m
Competitive		
Non-competitive		

Option C — Chemistry in industry and technology

C1. Aluminium is produced by the electrolysis of aluminium oxide.

(a) State how a low operating temperature is achieved when aluminium oxide is electrolysed. *[1]*

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. . . . . .

(b) Discuss **two** environmental concerns associated with the production of aluminium. *[2]*

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C2. The chlor-alkali industry also involves electrolysis.

(a) Identify **three** substances produced in this process and state a use for each. *[3]*

Substance	Use

(b) The mercury cell is sometimes used in the chlor-alkali industry. State the equation for the reaction occurring at the mercury electrode in this cell, including state symbols. *[1]*

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C3. Cracking is the process by which long-chain alkanes found in oil are broken down into smaller molecules.

(a) The following reaction occurs during the cracking of tetradecane, $C_{14}H_{30}$.

$$C_{14}H_{30}(g) \rightarrow C_{10}H_{22}(g) + 2C_2H_4(g)$$

Suggest a use for each of the products formed in the reaction. *[2]*

$C_{10}H_{22}$:

. . . . . .

. . . . . .

C_2H_4:

. . . . . .

. . . . . .

(b) State the main type of product obtained from steam cracking. *[1]*

. . . . . .

(c) Catalytic cracking uses silica as a heterogeneous catalyst. Explain the mode of action of a heterogeneous catalyst. *[2]*

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(d) State **one** advantage of using a heterogeneous catalyst rather than a homogeneous catalyst. *[1]*

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C4. Liquid crystals are sometimes used in the construction of "smart windows".

The windows are milky white in appearance as light is scattered by the randomly arranged liquid crystals. When a voltage is applied to the smart window, it becomes transparent as the liquid crystals align and allow the light to pass through without much scattering.

(a) State the property of the liquid-crystal molecules that allows them to align when a voltage is applied. *[1]*

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(b) List **two** substances that can behave as liquid crystals. *[1]*

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. . . . . .

(c) Distinguish between *thermotropic* and *lyotropic* liquid crystals. *[2]*

Thermotropic liquid crystals:

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. . . . . .
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Lyotropic liquid crystals:

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C5. Poly(propene) has different forms. Isotactic poly(propene) is tough, while atactic poly(propene) is flexible.

(a) (i) State the difference in the structure of the two polymers. *[1]*

Isotactic:

. . . . . .
. . . . . .

Atactic:

. . . . . .
. . . . . .

(ii) Explain how the difference in structure results in the different properties of isotactic and atactic poly(propene). *[2]*

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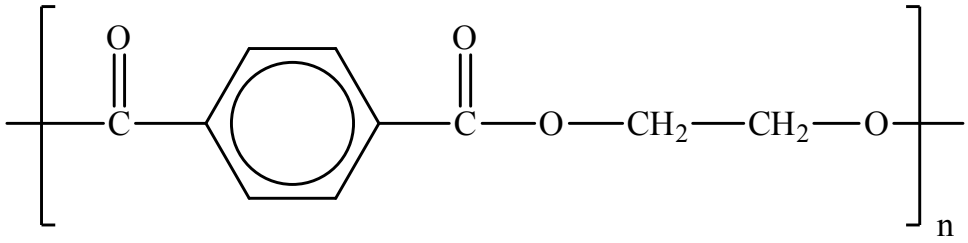
(This question continues on the following page)

(Question C5 continued)

(b) Polyethylene terephthalate (PET), represented below, is an example of a condensation polymer.



(i) Draw the structures of the monomers that form polyethylene terephthalate. *[2]*

(ii) Predict whether polyethylene terephthalate or isotactic poly(propene) has a higher melting point. Explain your answer in terms of intermolecular forces. *[3]*

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Option D — Medicines and drugs

D1. Depressants can have different effects depending on their doses.

(a) State **one** effect of a depressant at moderate dosage and **one** effect of a depressant at high dosage. *[1]*

Moderate dosage:

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High dosage:

. . . . . .

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(b) A breathalyser containing crystals of potassium dichromate(VI) can be used by the police to detect whether a driver has consumed alcohol.

(i) State the chemical formula for potassium dichromate(VI). *[1]*

. . . . . .

(ii) Describe the colour change observed during its reaction with ethanol. *[1]*

. . . . . .

(iii) State the oxidation number of chromium in the product. *[1]*

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(This question continues on the following page)

(Question D1 continued)

(iv) Deduce the **full** balanced chemical equation for the redox reaction of ethanol with acidified potassium dichromate(VI). *[2]*

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(v) State the name of the organic product formed. *[1]*

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(c) An intoximeter is used to determine an accurate value for the concentration of ethanol in the breath. Explain **one** technique used for the detection of ethanol in an intoximeter. *[3]*

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D2. Stimulants are often classified as psychoactive drugs.

(a) List **two** physiological effects of stimulants. *[1]*

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(b) Amphetamine and epinephrine (adrenaline) are chemically similar in that both compounds are derived from the phenylethylamine structure. The structures of both compounds can be found in Table 20 of the Data Booklet.

(i) Draw the structure of the phenyl group. *[1]*

(ii) Identify which compound contains a primary amine. *[1]*

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D3. Many factors can be involved in the action of a particular drug.

(a) Geometrical isomerism can play a key role in drug action. One of the first platinum(II) anti-cancer drugs to be developed was cisplatin. In contrast, transplatin was found to be ineffective in the treatment of testicular and ovarian cancer.

(i) State the shape of the $Pt(NH_3)_2Cl_2$ complex. *[1]*

. . . . . .

(ii) Draw the **two** geometrical isomers of $Pt(NH_3)_2Cl_2$. *[1]*

Cisplatin	Transplatin

(iii) State the value of the Cl–Pt–Cl bond angle for each isomer. *[1]*

Cisplatin:

. . . . . .

Transplatin:

. . . . . .

(This question continues on the following page)

(Question D3 continued)

(iv) Deduce which geometrical isomer is polar, using a suitable diagram to support your answer. *[1]*

(v) State a reason why cisplatin might be more effective in the treatment of cancer than transplatin, even though they have the same basic shape. *[1]*

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(b) The structures of morphine and diamorphine (heroin) are given in Table 20 of the Data Booklet. With reference to the structures, explain why diamorphine (heroin) is more potent than morphine. *[3]*

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(Question D3 continued)

(c) The molecular polarity of a drug can control its efficiency. Explain, using the examples of aspirin and fluoxetine hydrochloride, how the polarity of a drug can be modified in order to increase its aqueous solubility and distribution around the body. The structures of aspirin and fluoxetine hydrochloride are given in Table 20 of the Data Booklet. *[4]*

Aspirin:

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Fluoxetine hydrochloride (Prozac®):

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Option E — Environmental chemistry

E1. Increasing concentrations of greenhouse gases are considered to cause global warming. Ozone depletion is another environmental concern.

(a) Identify a gas that is both a greenhouse gas and a cause of ozone depletion. *[1]*

. . . . . .

(b) Outline **one** impact of each environmental concern and suggest a way to reduce it. *[4]*

Environmental Concern	Impact	Way to reduce impact
Global warming	. . . . .	. . . . .
Ozone depletion	. . . . .	. . . . .

(This question continues on the following page)

(Question E1 continued)

(c) Ozone and oxygen are in equilibrium in the stratosphere. Both gases absorb ultraviolet radiation and dissociate producing oxygen atoms.

Describe the dependence of ozone and oxygen dissociation on the wavelength of radiation absorbed, and explain how this is related to the bonding in each molecule. *[3]*

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E2. Societies have the option of different methods for waste disposal.

(a) Compare landfills with incineration as methods for waste disposal. *[4]*

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(b) State **two** types of solid waste that can be recycled. *[1]*

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E3. Nitrogen monoxide gas, NO, is emitted by cars and leads to acid deposition.

(a) Discuss the damage to the environment caused by acid deposition. *[3]*

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(b) A catalytic converter can reduce emissions of nitrogen monoxide. Identify the type of reaction that occurs in the catalytic converter and state a chemical equation to illustrate your answer. *[2]*

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. . . . . .
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(c) The mechanism of the formation of nitric(V) acid, HNO_3, from nitrogen monoxide involves the hydroxyl free radical. Describe this mechanism with equations, including the formation of the hydroxyl free radical. *[3]*

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E4. Heavy metal ions are pollutants that can be removed in the tertiary stage of waste water treatment.

A water sample at 25 °C contains lead and sulfate ions in the following concentrations:

$$[Pb^{2+}] = 2.32 \times 10^{-6} \text{ mol dm}^{-3}$$

$$[SO_4^{2-}] = 4.15 \times 10^{-3} \text{ mol dm}^{-3}$$

The solubility product constant, K_{sp}, of lead sulfate is 1.80×10^{-8} at 25 °C.

(a) State the expression for the solubility product constant, K_{sp}, of lead sulfate. *[1]*

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. . . . . .

(b) Deduce why lead sulfate will not precipitate out of the water sample at these concentrations. *[1]*

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(c) Some magnesium sulfate is added to the water sample. Determine the increase in sulfate ion concentration needed for lead sulfate to precipitate. *[2]*

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Option F — Food chemistry

F1. Antioxidants occur naturally (such as vitamin C) or can be synthetic.

(a) Define the term *antioxidant*. *[1]*

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. . . . . .

(b) (i) Identify an element that is a common naturally occurring antioxidant. *[1]*

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(ii) State **one** food in which this antioxidant can occur. *[1]*

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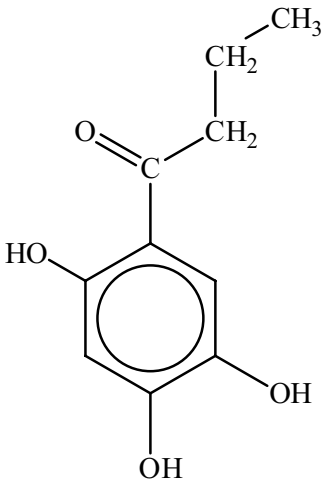
(This question continues on the following page)

(Question F1 continued)

(c) The structures of three synthetic antioxidants, 2-BHA, 3-BHA and BHT are given in Table 22 of the Data Booklet. Another synthetic antioxidant is THBP whose structure is shown below.



THBP

(i) Deduce which of these four antioxidants contain the phenol group. *[2]*

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(ii) Deduce whether THBP contains the tertiary butyl group or not. *[1]*

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. . . . . .

(iii) Suggest the function of the tertiary butyl group in antioxidants. *[1]*

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F2. The food industry uses food-grade dyes and pigments to increase the appeal of food products.

(a) State the difference in terms of solubility between a dye and a pigment. *[1]*

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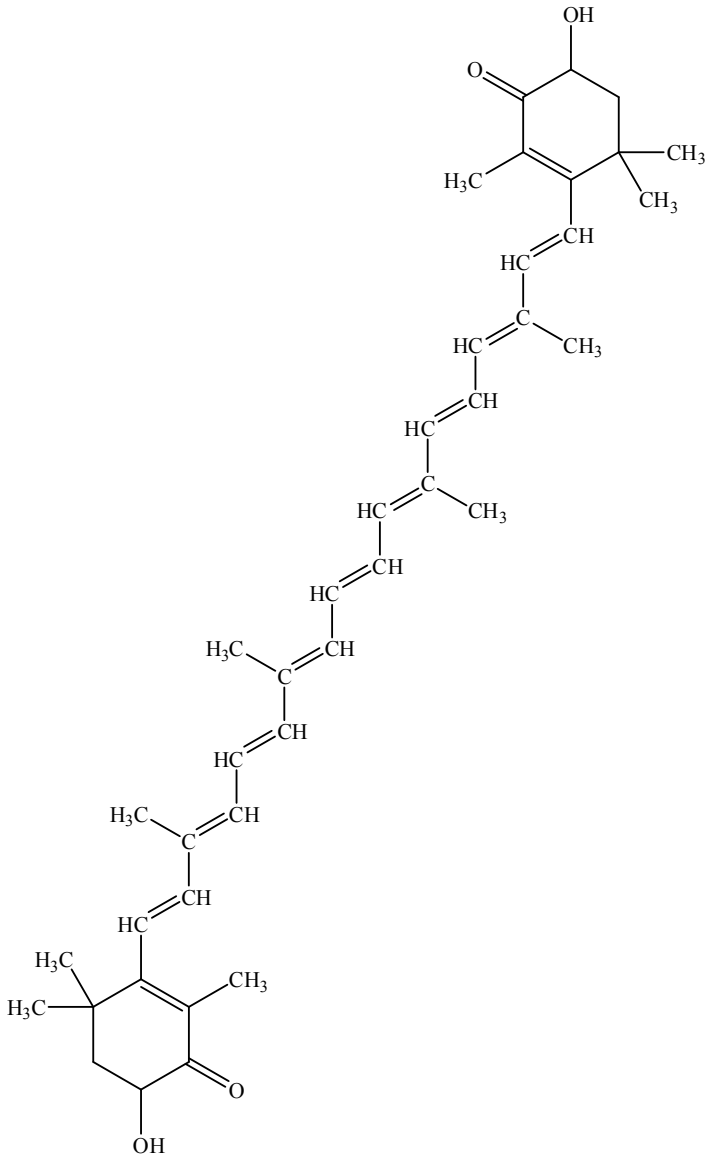
(b) The pigment associated with the olive-green colour of the outer shell of the American lobster is astaxanthin, shown below. When cooked the lobster changes to a red colour.



Astaxanthin

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(Question F2 continued)

(i) Identify the class of pigment to which astaxanthin belongs. *[1]*

. . . . . .

(ii) Explain why the properties of pigments in the shell of a live lobster can lead to colour variation (for example, from olive-green to orange). *[1]*

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(iii) Explain how the colour of astaxanthin changes to red when cooked. *[2]*

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F3. The Maillard reaction is the basis of non-enzymatic browning and involves the reaction between carbohydrates and proteins.

(a) The first step of this reaction involves a condensation reaction between a reducing sugar, such as glucose, and an amino acid.

(i) Using RCHO to represent glucose and H_2NR' to represent an amino acid, deduce the structural formula of the product. *[1]*

. . . . . .
. . . . . .

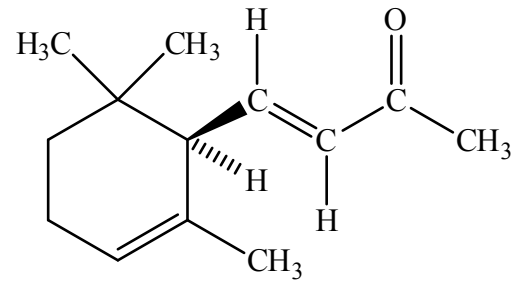
(ii) Identify the other product of this reaction. *[1]*

. . . . . .

(b) Other than condensation, state the name of **one** type of reaction involved in the other two steps of the Maillard reaction. *[1]*

. . . . . .

F4. The structure below shows an enantiomer of α-ionone, which has a raspberry flavour.



represents bond behind the plane

represents bond in front of the plane

(a) Identify the chiral centre in the structure above with an asterisk (*). *[1]*

(b) Explain what is meant by the R, S notation and how this is different to the +(*d*) and –(*l*) notation. *[2]*

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. . . . . .
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(c) Deduce whether the enantiomer shown is R or S and explain your answer. *[2]*

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(This question continues on the following page)

(Question F4 continued)

(d) Another enantiomer of α-ionone has a different flavour. Suggest a reason for this difference. *[1]*

. . . . . .
. . . . . .

(e) Two other optical isomers which have an effect on flavour are +(*d*) and –(*l*) limonene. State the flavour associated with each enantiomer. *[1]*

+(*d*) limonene:

. . . . . .

–(*l*) limonene:

. . . . . .

F5. Auto-oxidation is the chemical process responsible for the rancidity of butter.

(a) Using RH as the formula for the fat in butter, state **three** equations associated with the reaction of RH with oxygen, resulting in the formation of hydroperoxide. *[2]*

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(b) In this process the hydroperoxides act as intermediates. State why they degrade and rearrange to other compounds and identify a functional group in these compounds. *[1]*

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Option G — Further organic chemistry

G1. Benzene, C_6H_6, is found naturally in crude oil.

(a) Describe the chemical structure of benzene. *[3]*

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(b) State and explain the relative rates of hydrolysis of (bromomethyl)benzene, $C_6H_5CH_2Br$, and bromobenzene, C_6H_5Br. *[3]*

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G2. Deduce the structural formulas of the major products, **A**–**D**, formed in the following reactions.

(a) (i) $CH_3CH_2CHO + HCN \rightarrow \mathbf{A}$ *[1]*

A:

(ii) $\mathbf{A} + H_3O^+ \rightarrow \mathbf{B}$ *[1]*

B:

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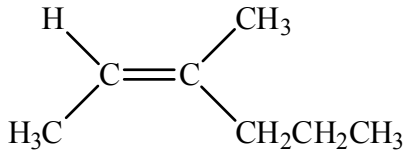
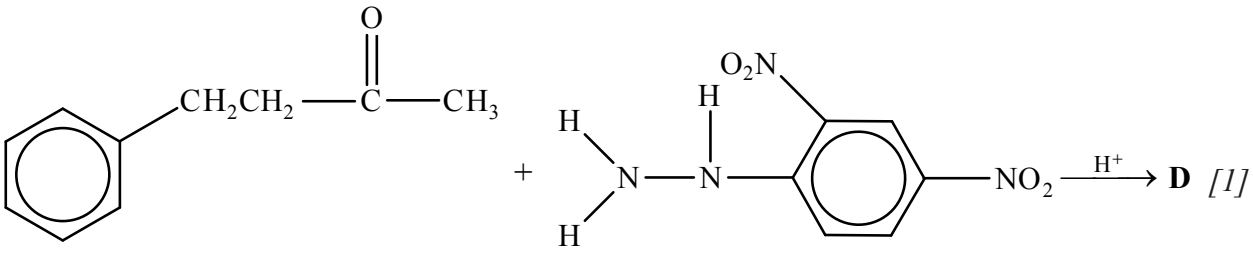
(Question G2 continued)

(b)  + HBr → **C** *[1]*

C:

(c)  *[1]*

D:

G3. Elimination reactions are an important type of reaction in organic chemistry.

(a) Describe, using curly arrows to represent the movement of electron pairs, the mechanism of the reaction of butan-1-ol, $CH_3(CH_2)_3OH$, with concentrated phosphoric acid, H_3PO_4. *[4]*

(b) Suggest why it is better to use phosphoric acid, H_3PO_4, instead of sulfuric acid, H_2SO_4, in this reaction. *[1]*

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G4. (a) Describe and explain, using curly arrows to represent the movement of electron pairs, the mechanism of the reaction of benzene with chlorine using a suitable Lewis acid catalyst. *[4]*

(b) (i) Draw the structures of the **major** organic products formed from the reaction of methylbenzene with chlorine (in the dark), using a suitable Lewis acid catalyst. *[1]*

(ii) Explain why these particular products are the major products. *[2]*

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(Question G4 continued)

(c) Starting with benzene, deduce a two-stage reaction pathway to form 1-ethyl-4-methylbenzene. Draw the structures of the products formed in each stage and identify all reagents used, including any catalysts involved. *[3]*

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